



Fundamental Inlet Bleed Experiments (FIBE)

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Agenda

- FIBE Overview
- Facility Overview
- Phase I Summary
- Phase II Results
- Phase III Planning
 - 15x15cm Bleed Capacity Upgrade
 - 15x15cm Axisymmetric Test Section



FIBE Overall Objective

- The Fundamental Inlet Bleed Experiments (FIBE) project is primarily an experimental program to establish a comprehensive experimental bleed database to advance the understanding of how bleed systems can be improved through:
 - Improved bleed modeling (Design and CFD)
 - Bleed placement within a high-speed inlet
 - Alternate bleed configurations
 - Bleed orifice inlet conditioning
 - Non-circular bleed orifices
 - Bleed patterns



Slot Array

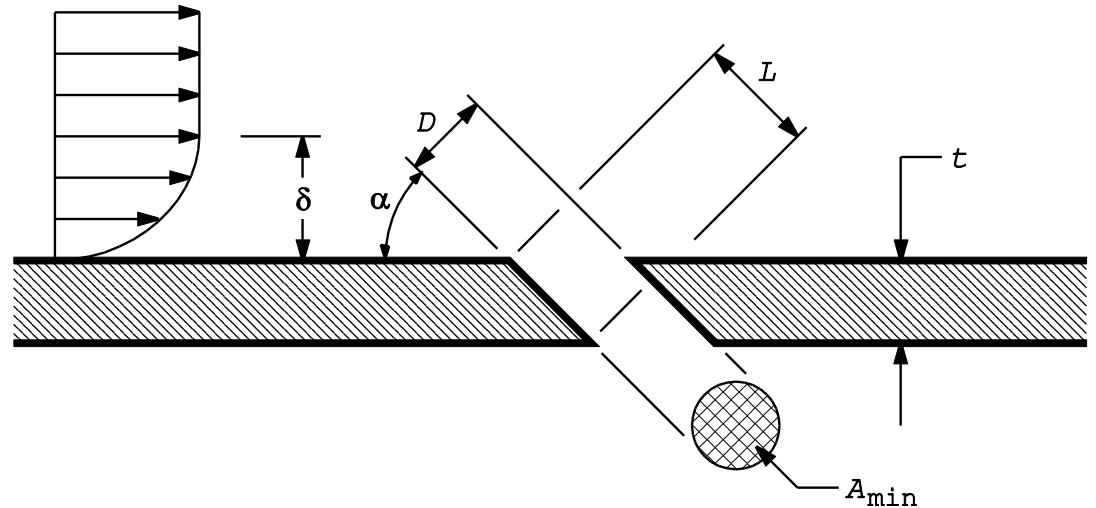
Radiused
Edges

Bleed Hole Parameters

“Thick” Bleed Plate

$$\frac{t}{D} \geq \cos \alpha$$

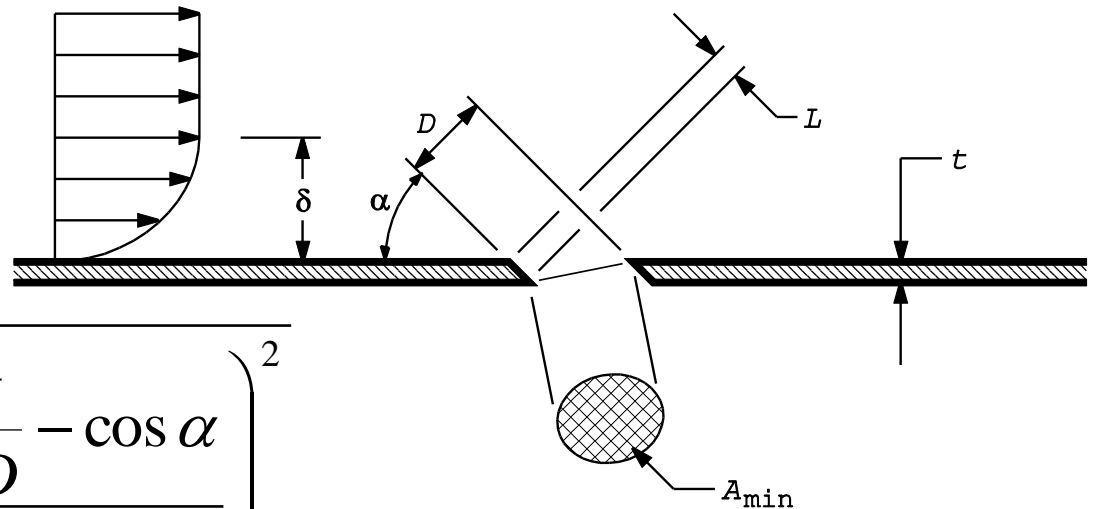
$$A_{\min, \text{thick}} = A_b = \frac{\pi}{4} D^2$$



“Thin” Bleed Plate

$$\frac{t}{D} < \cos \alpha$$

$$A_{\min, \text{thin}} = A_b \sqrt{\left(\frac{t}{D}\right)^2 + \left(\frac{\frac{t}{D} - \cos \alpha}{\sin \alpha}\right)^2}$$





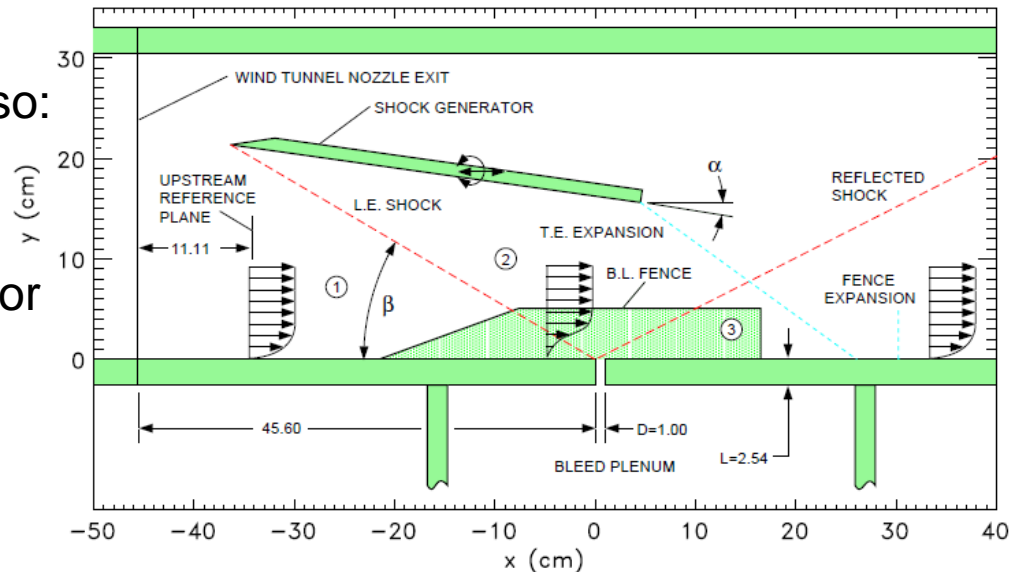
FIBE Phase Objectives

- The FIBE program will be conducted in three phases. The primary objectives for each phase are:
 - Phase I - 15x15cm Supersonic Wind Tunnel (SWT)
 - Checkout of facility, bleed system, and instrumentation.
 - Document approach flow conditions for this and subsequent Phases.
 - Obtain flow coefficient data for pre-existing single-hole test articles.
 - Phase II – 15x15cm SWT
 - Obtain flow coefficient data for single-hole or non-interacting multi-hole configurations.
 - Inclination Angle
 - L/D
 - D/δ^*
 - Dynamic Plenum Pressure Measurements



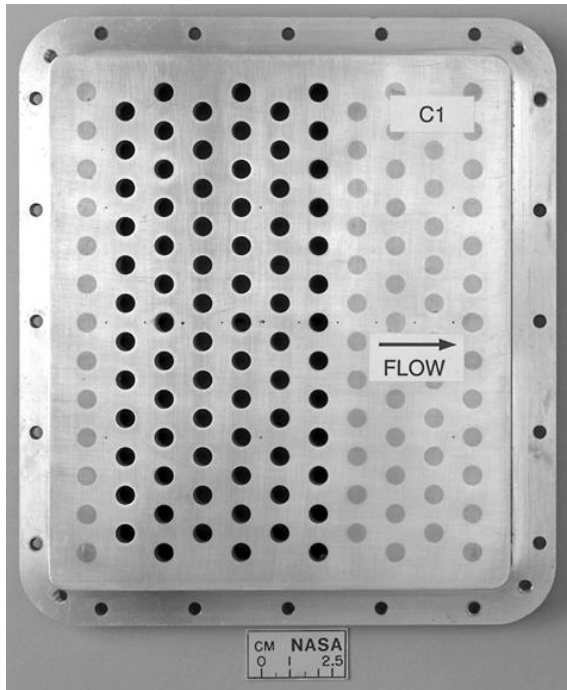
FIBE Phase Objectives

- Phase III - 15x15cm SWT
 - Full bleed regions without and with oblique or normal shock using multi-hole patterns with similar geometry as Phase II single-hole tests.
 - Flow coefficient
 - Downstream flow-field measurements
 - Dynamic Plenum and Surface Pressure Measurements
 - Facility Upgrades
 - Reinstall and upgrade ejector system.
 - Larger bleed lines.
- Phase III – 1x1ft SWT
 - Similar data as above but also:
 - Glancing interaction
 - Corner interaction
 - Bleed system/shock generator assembly require some minor additional component fabrication.





Flow Coefficient Scaling

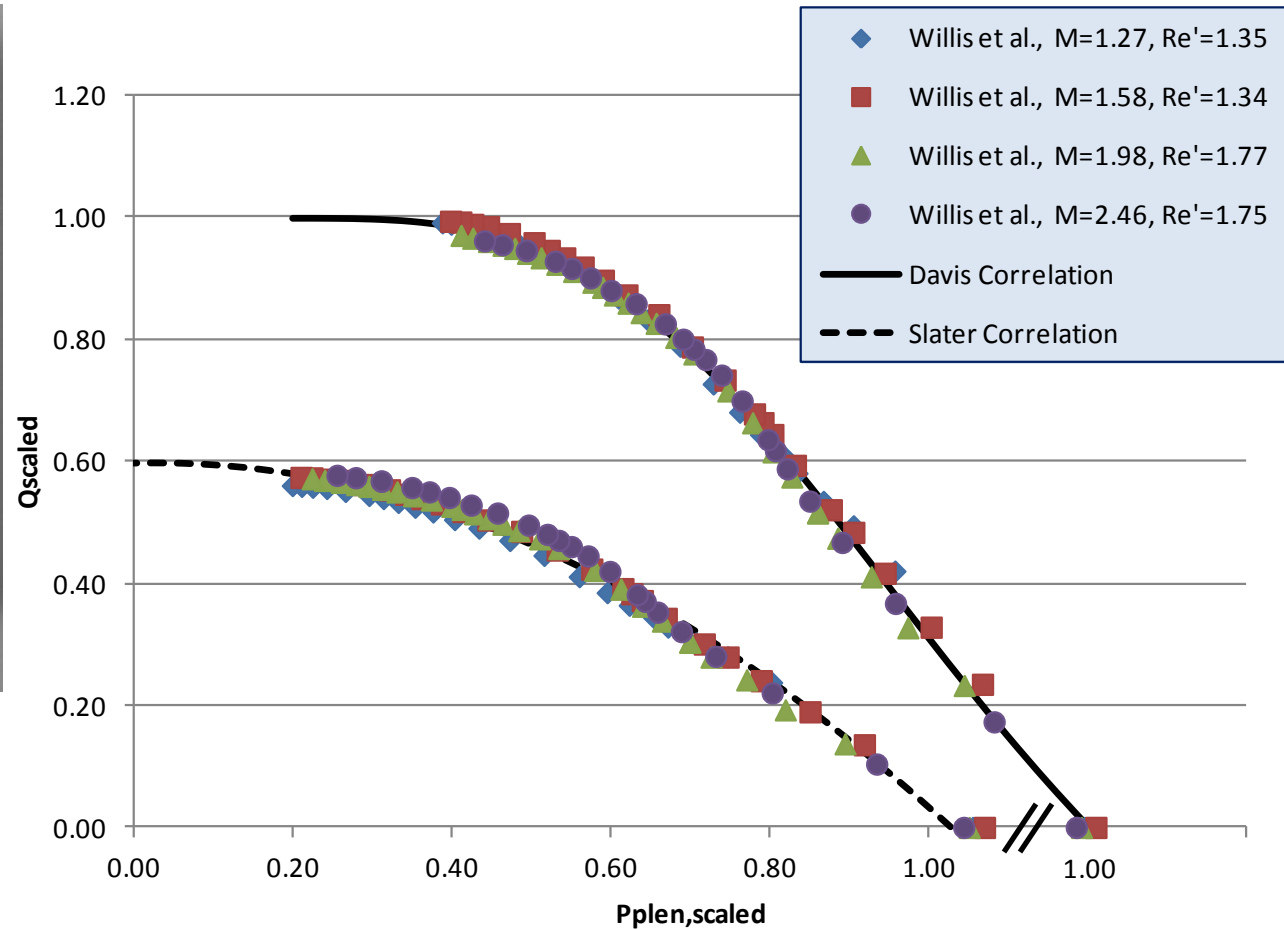


$$\alpha=90^\circ$$

$$L/D=1$$

$$D/\delta^*\sim 1$$

20% Porosity



Correlations based on multi-hole data of Willis et al.

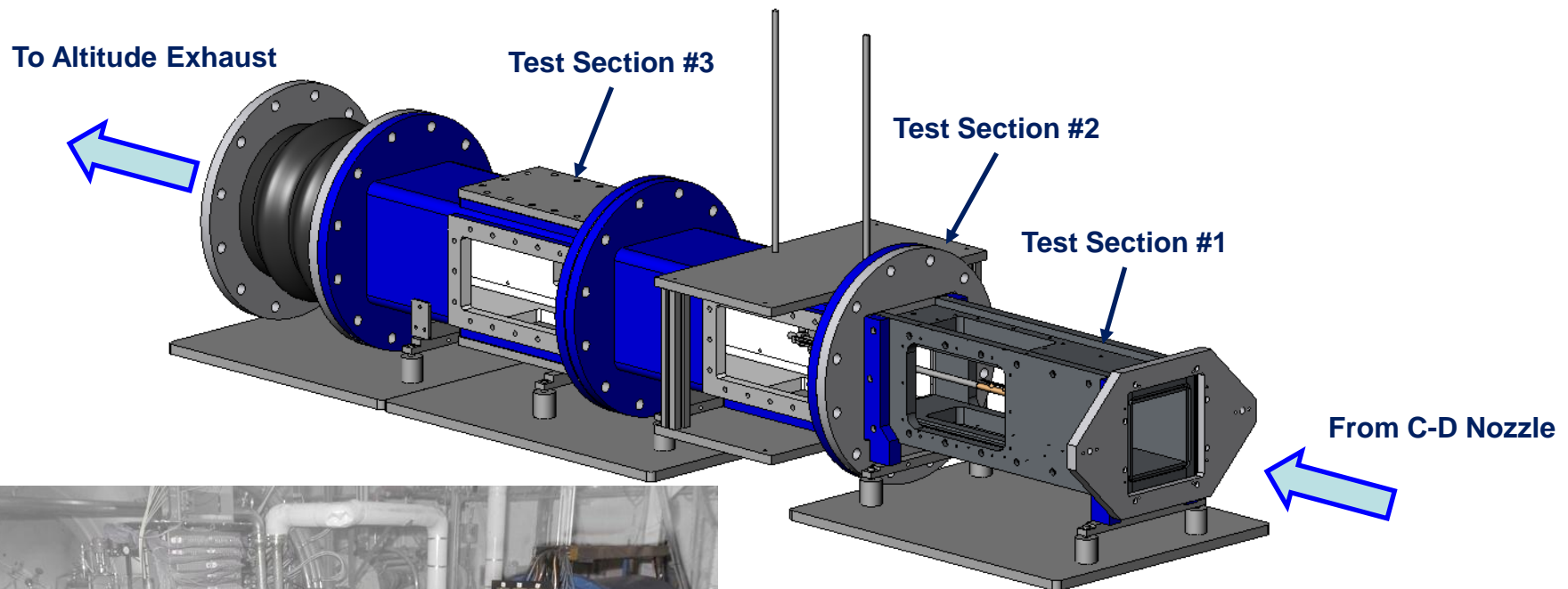


FACILITY OVERVIEW

15x15cm Supersonic Wind Tunnel



15x15cm Supersonic Wind Tunnel

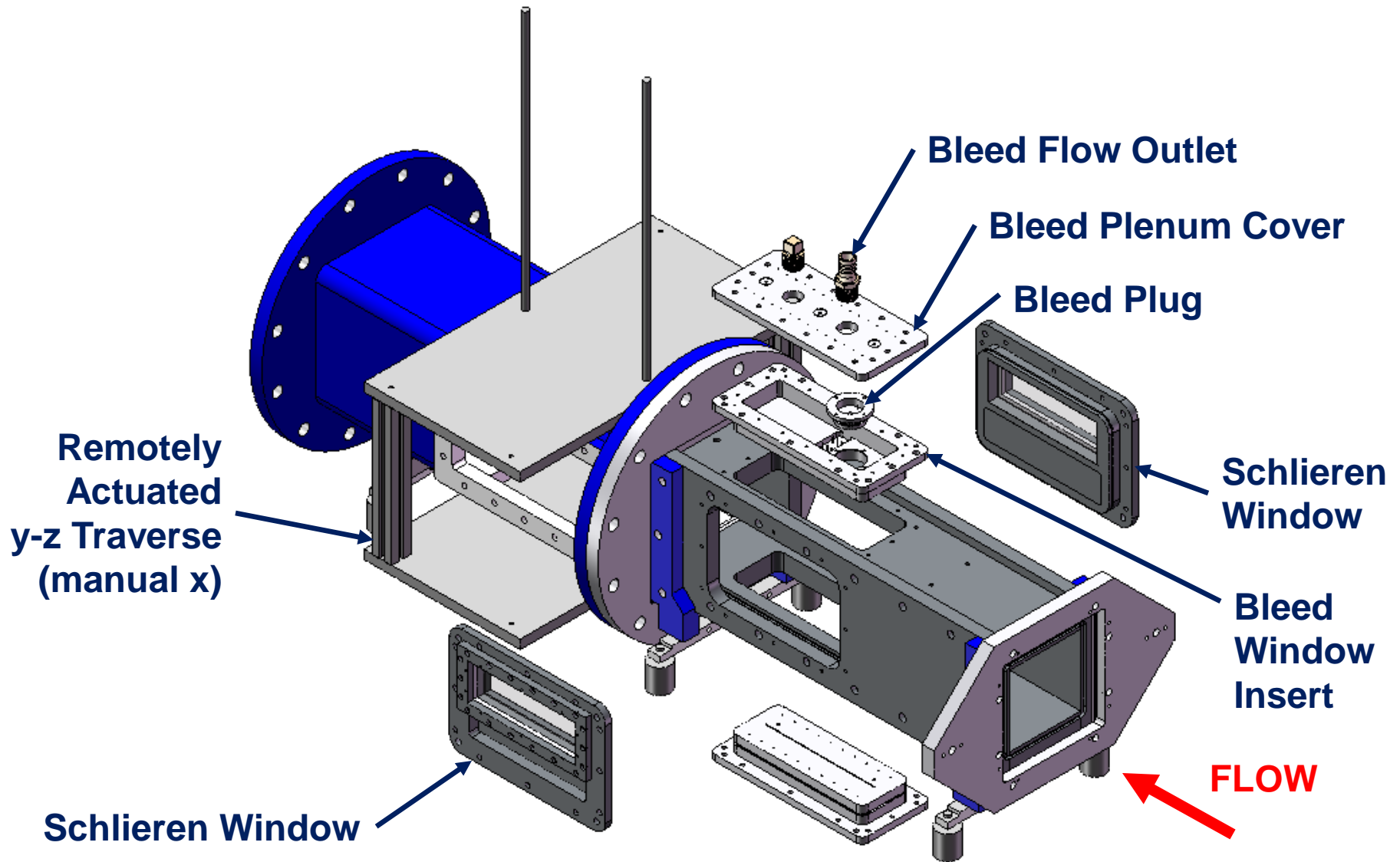


15x15 cm Supersonic Wind Tunnel

- Continuous Flow
- Fixed Geometry Nozzle Blocks
 - Blocks rotatable so “good” B.L. can be on horizontal or vertical walls.
- 40psig Combustion Air Supply
- Ambient Total Temperature

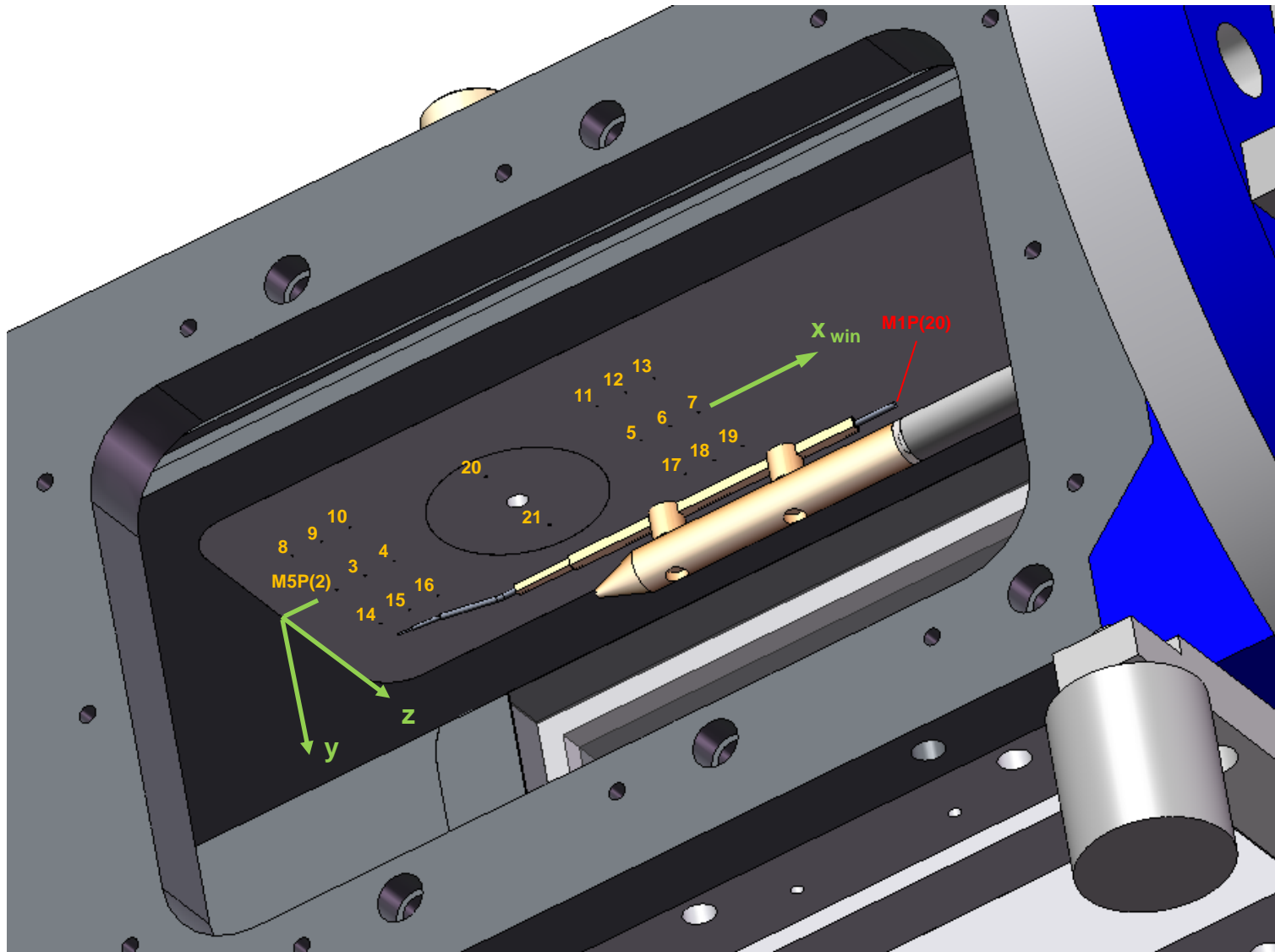


Test Section Window Configuration



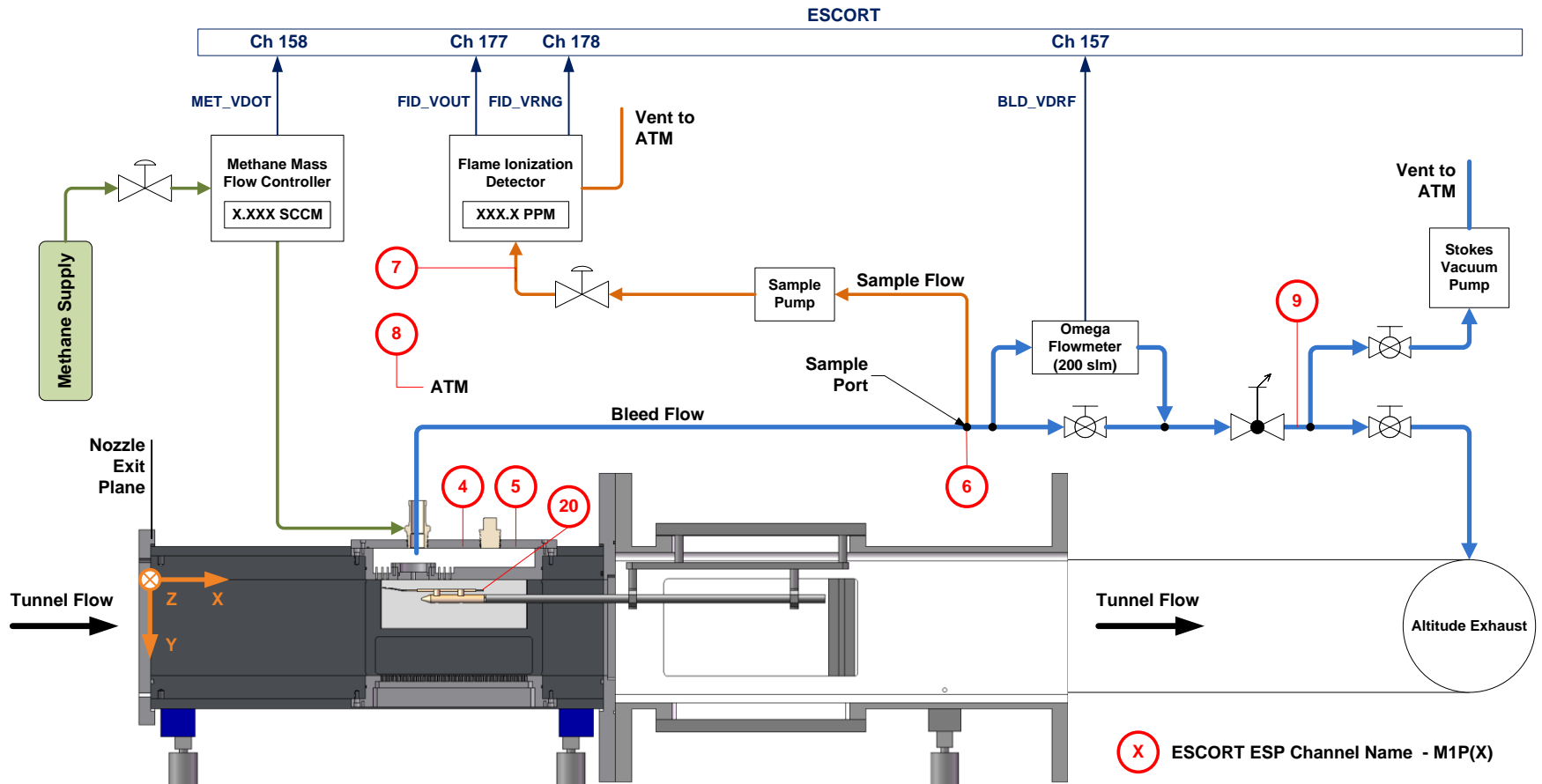


Top Window Static Taps





FIBE Test Schematic



“Method-of-Mixtures”

$$w_{air} = \left(\frac{M_{air}}{M_{met}} \right) \left(\frac{1 - v_{met}}{v_{met}} \right) w_{met}$$

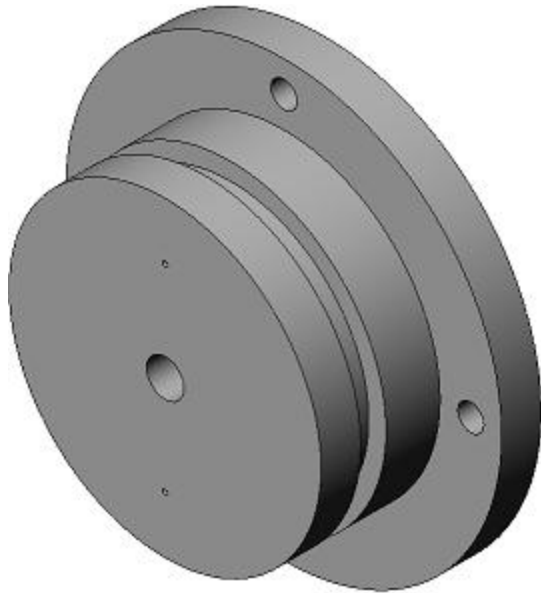


FIBE PHASE I SUMMARY

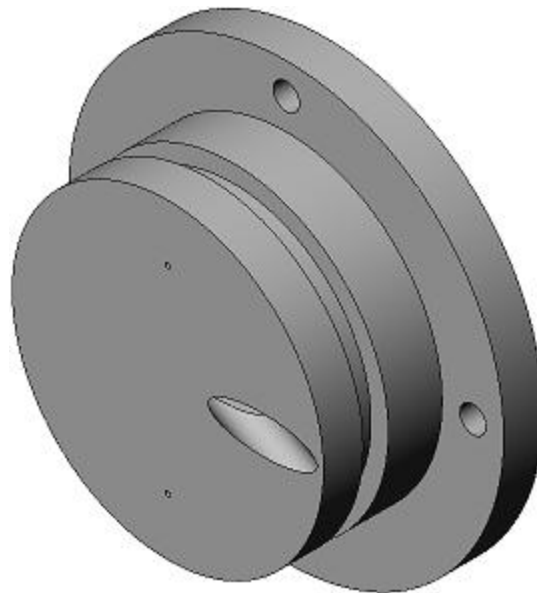
Results Summarized in AIAA Paper 2012-0272



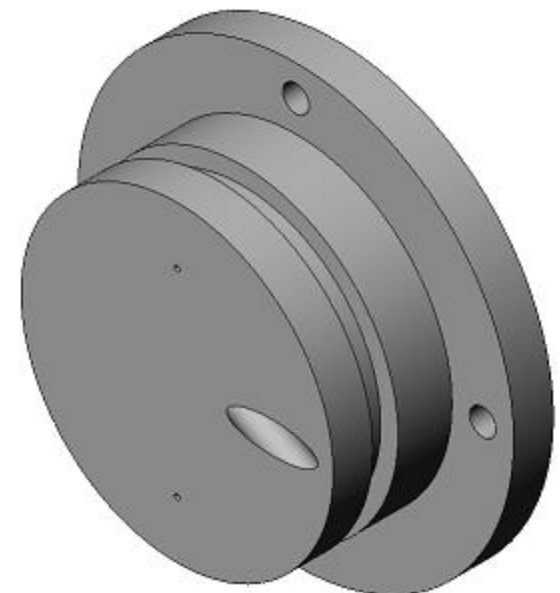
Pre-Existing Test Articles



C01
D=6.010mm
 $\alpha=90^\circ$
L/D=2.0
t/D=2.0
A/A_b=1.00



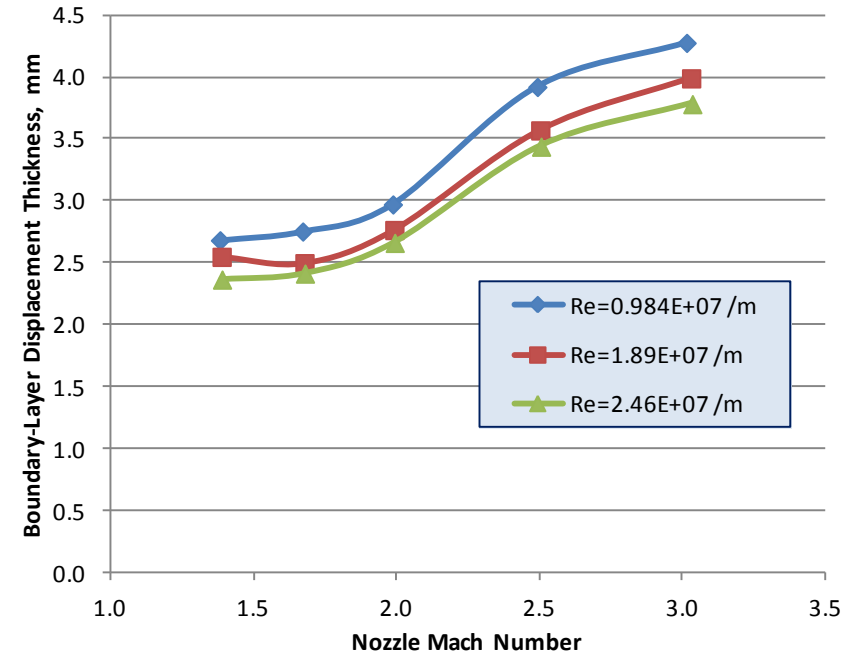
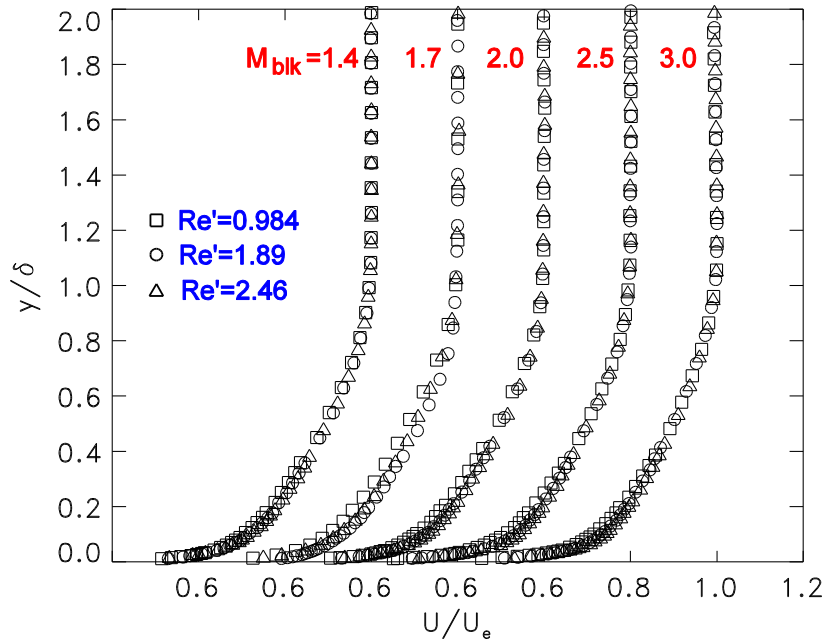
C02
D=6.029mm
 $\alpha=20^\circ$
L/D=2.0
t/D=0.684
A/A_b=1.248



C03
D=5.018mm
 $\alpha=20^\circ$
L/D=2.92
t/D=1.0
A/A_b=1.0



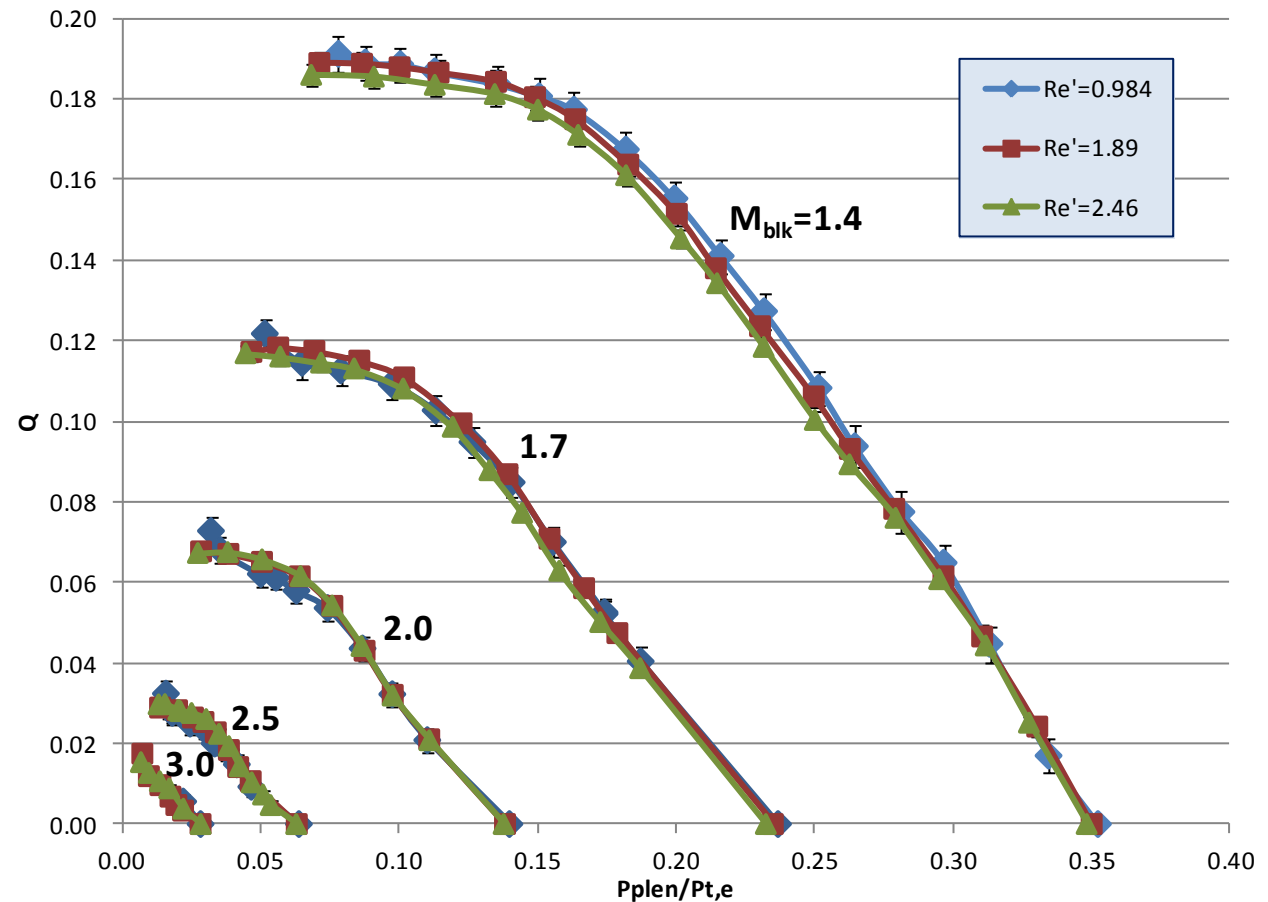
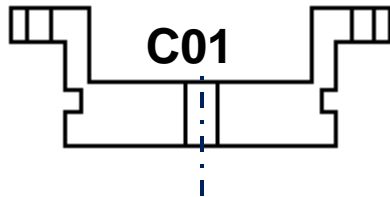
Approach Boundary-Layer Profiles



Displacement thickness variation is consistent with Reynolds number.



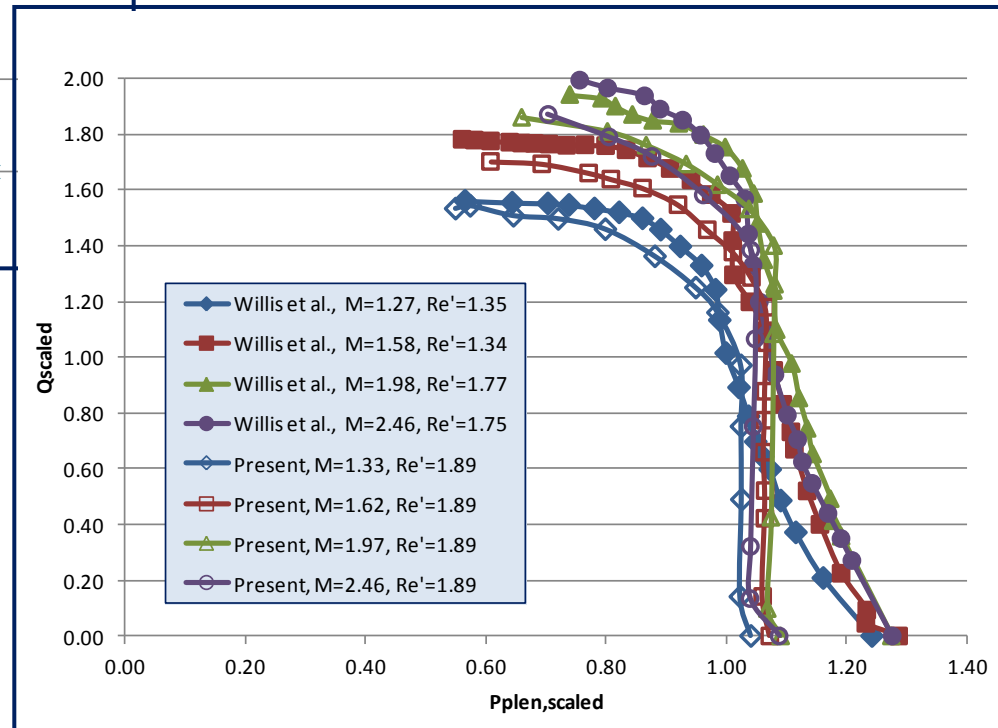
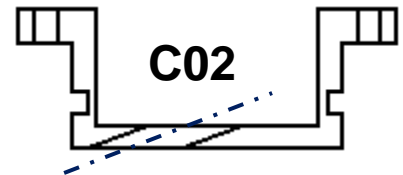
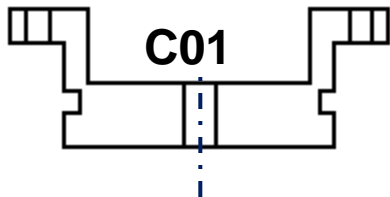
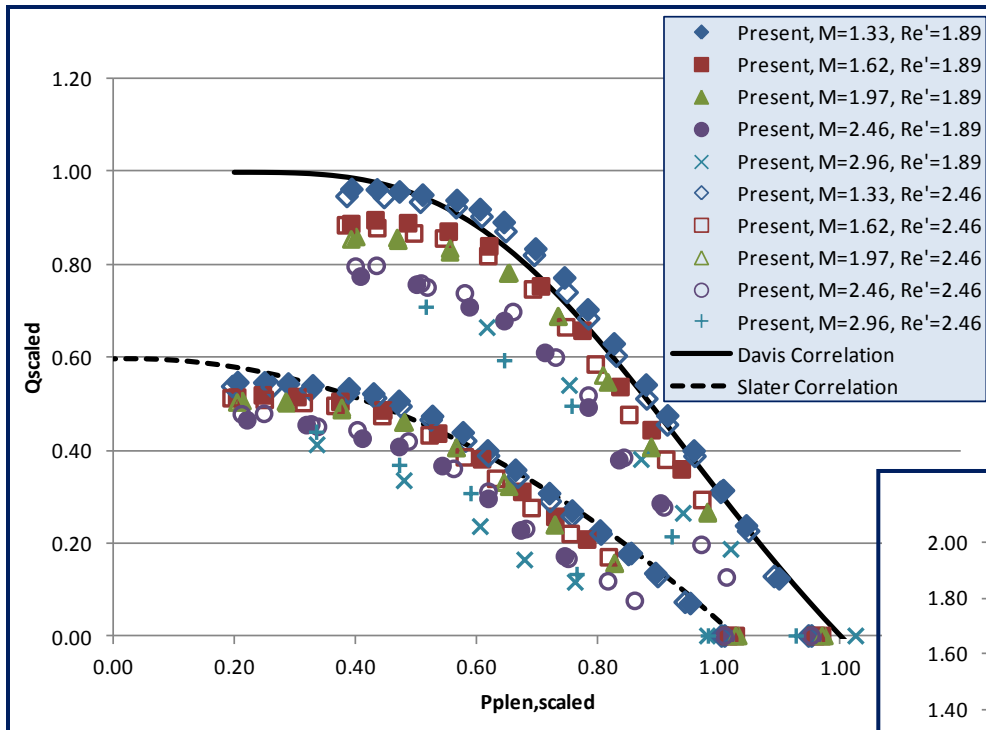
Reynolds Number Dependence



- Tail-up behavior due to sample pump limitation
- Generally there is only a small Reynolds number dependence.



Flow Coefficient Scaling





Phase I Conclusions

- Approach flow conditions established for all Mach numbers and Reynolds numbers.
- Results only weakly dependent on Reynolds number.
- Static pressure scaling:
 - $\alpha=90^\circ$ - Data collapses but not quite as good as multi-hole data of Willis et al.
 - $\alpha=20^\circ$ - As anticipated, data does not collapse.



FIBE PHASE II RESULTS

Results Summarized in AIAA Paper 2013-0272

and

M. Eichorn's MS Thesis (CWRU, In Progress)



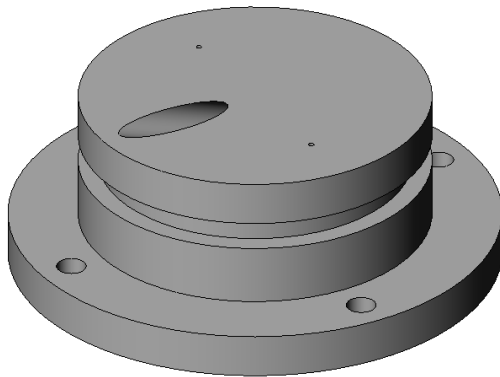
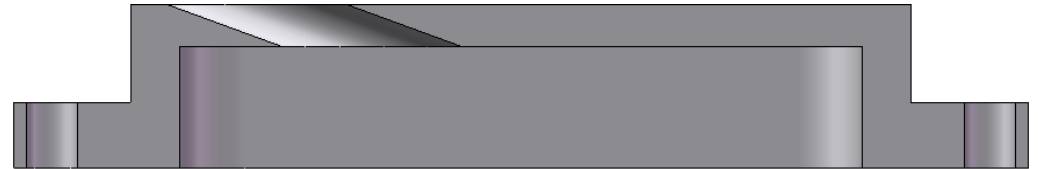
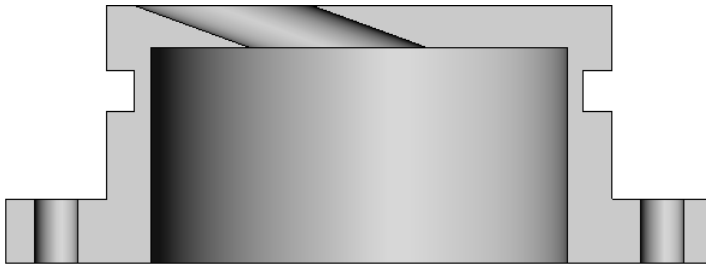
Geometry Variavles

- Parameters: α , D , t/D
- Ranges permitted:
 - α – 20° to 90°
 - D – 0.794 to 6.35 mm (0.0313 to 0.250 in)
 - t – 0.893 to 12.7 mm (0.0352 to 0.500 in)
 - t/D – 0.250 to 2.000
- Results in:
 - L/D – 0.250 to 5.85
 - D/δ^* – 0.210 to 2.68



FIBE Phase II Hardware

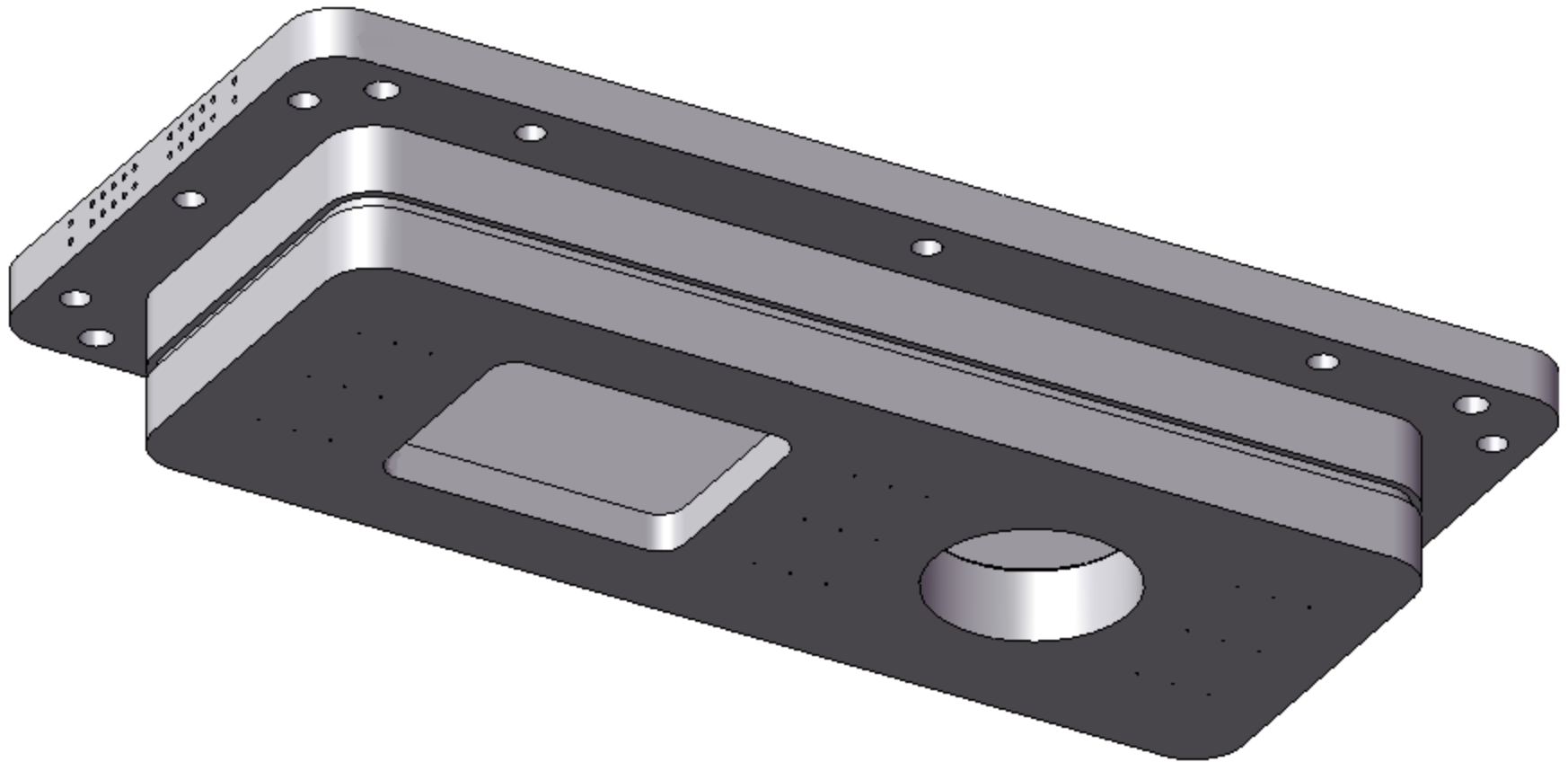
- Bleed “Plugs” from Phase I were replaced with Bleed “Plates” for Phase II which will allow more flexibility in bleed configurations.





FIBE Phase II Hardware

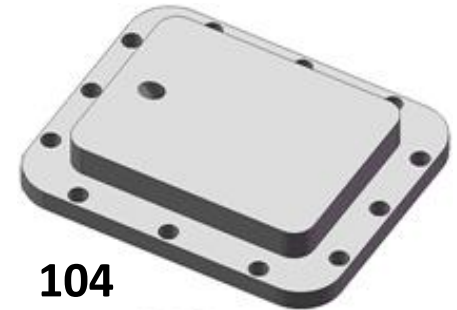
- Phase I top wall is being modified to accept new Bleed Plates. Either Plug or Plate can be used by reversing top wall.



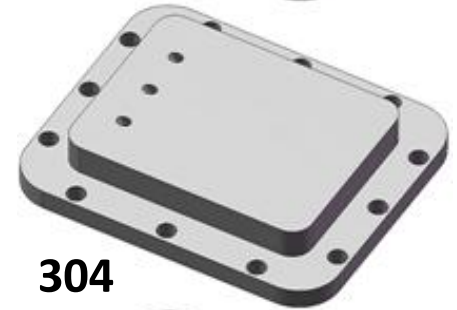


Test Configurations

Config.	Alpha	D (mm)	t (mm)	t/D	L/D	N	Amin/Ab
101	90	6.350	12.700	2.000	2.000	1	1.0
102	90	6.350	7.144	1.125	1.125	1	1.0
103	90	6.350	1.588	0.250	0.250	1	1.0
104	55	6.350	12.700	2.000	2.442	1	1.0
105	55	6.350	7.144	1.125	1.373	1	1.0
106	55	6.350	1.588	0.250	0.305	1	1.1
107	20	6.350	12.700	2.000	5.848	1	1.0
108	20	6.350	7.144	1.125	3.289	1	1.0
109	20	6.350	1.588	0.250	0.731	1	2.3
301	90	3.572	7.144	2.000	2.000	3	1.0
302	90	3.572	4.018	1.125	1.125	3	1.0
303	90	3.572	0.893	0.250	0.250	3	1.0
304	55	3.572	7.144	2.000	2.442	3	1.0
305	55	3.572	4.018	1.125	1.373	3	1.0
306	55	3.572	0.893	0.250	0.305	3	1.1
307	20	3.572	7.144	2.000	5.848	3	1.0
308	20	3.572	4.018	1.125	3.289	3	1.0
309	20	3.572	0.893	0.250	0.731	3	2.3
1501	90	0.794	1.588	2.000	2.000	15	1.0
1504	55	0.794	1.588	2.000	2.442	15	1.0
1507	20	0.794	1.588	2.000	5.848	15	1.0



104



304



1504



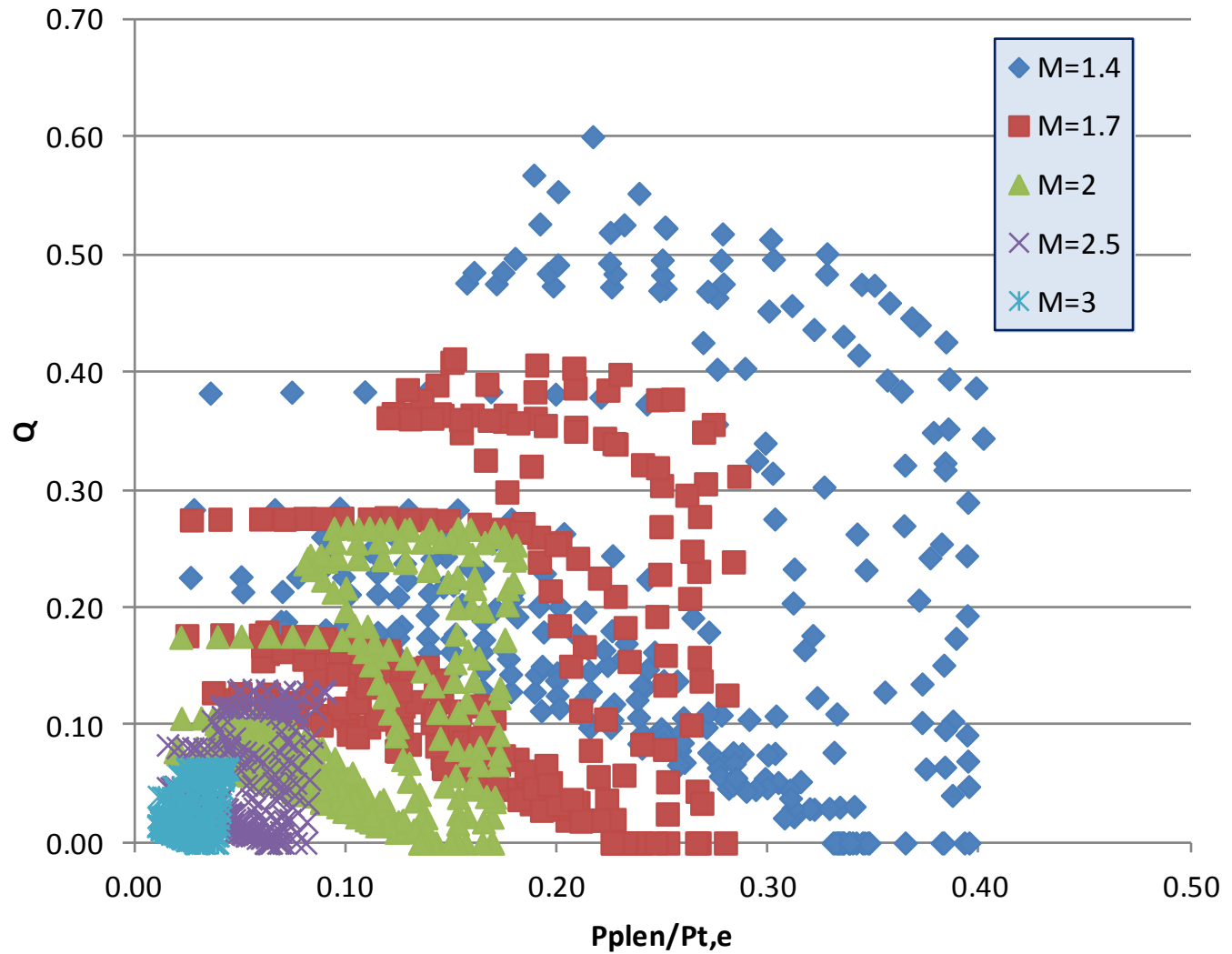
FIBE Phase II – Test Article Matrix

101		104		107	
102		105		108	
103		106		109	
301		304		307	
302		305		308	
303		306		309	
1501		1504		1507	



FIBE Phase II Data

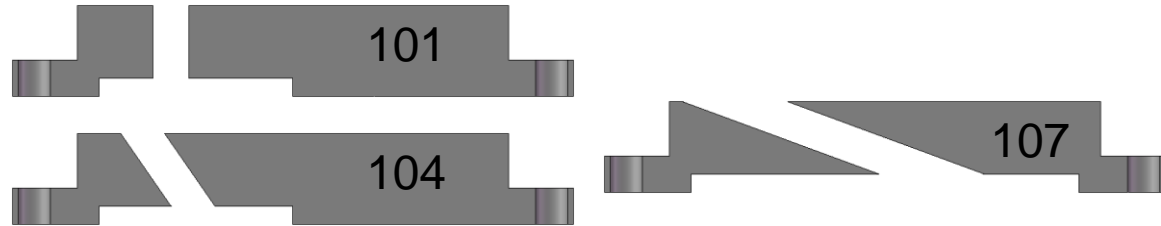
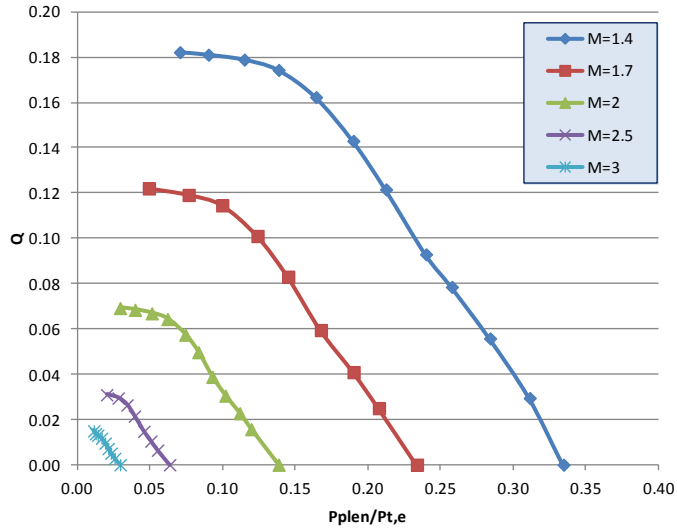
All Data



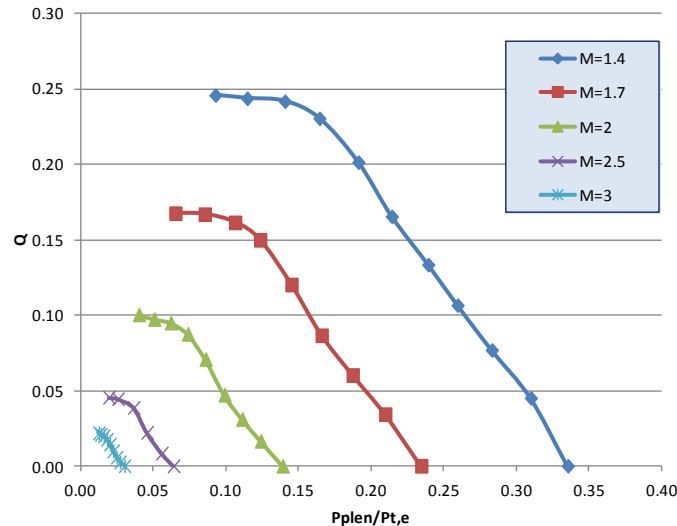


Effect of Mach Number

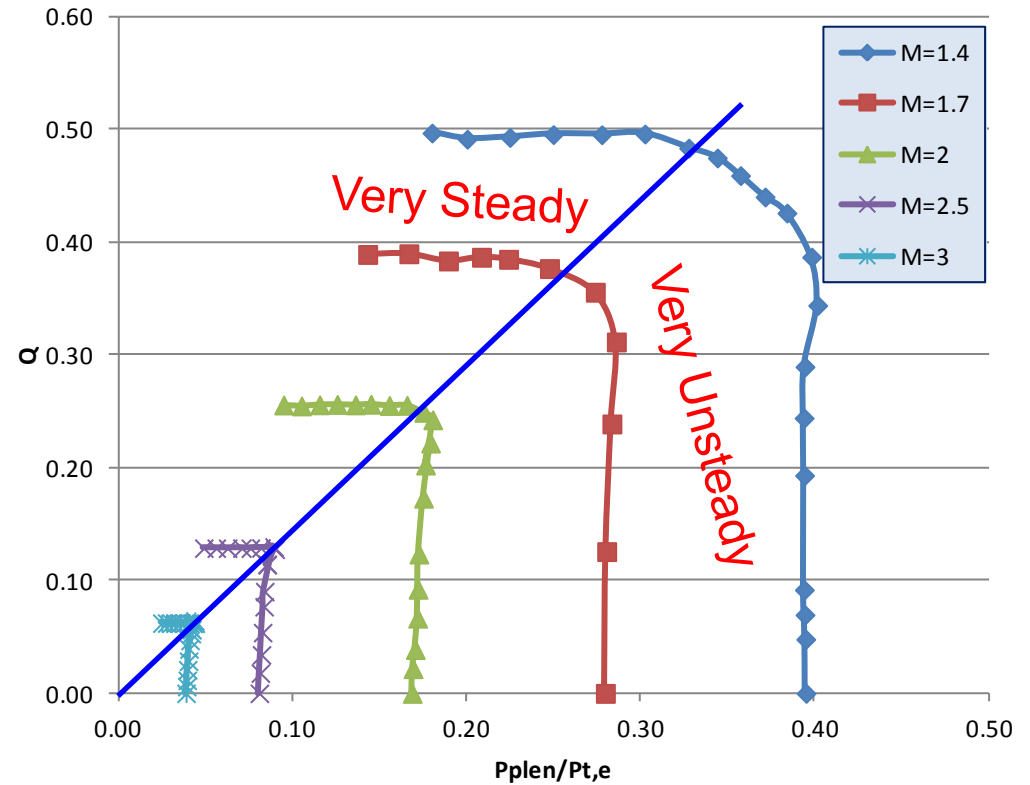
C101, 90 deg., $t/D=2$



C104, 55 deg., $t/D=2$



C107, 20 deg., $t/D=2$

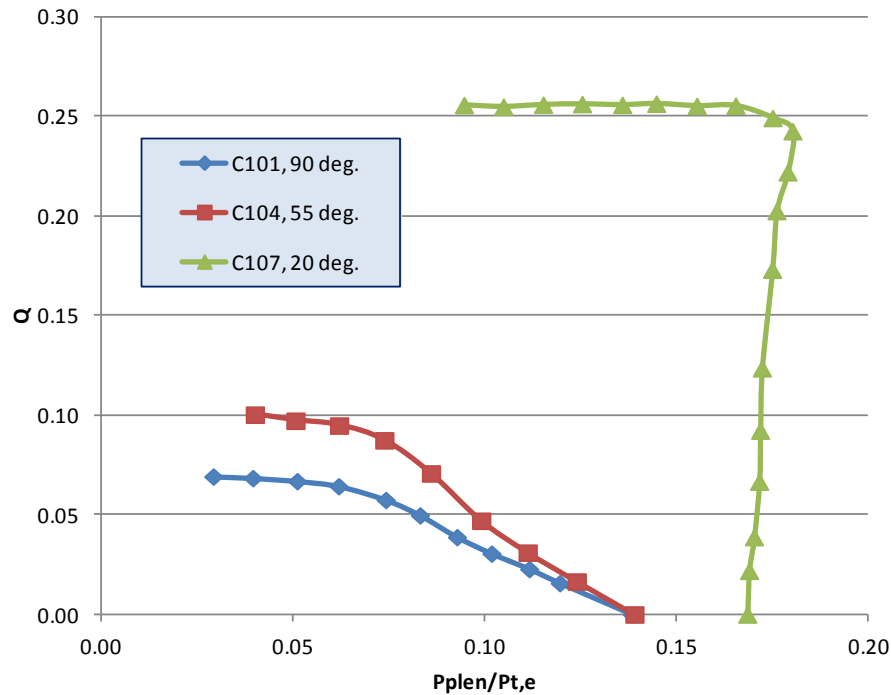




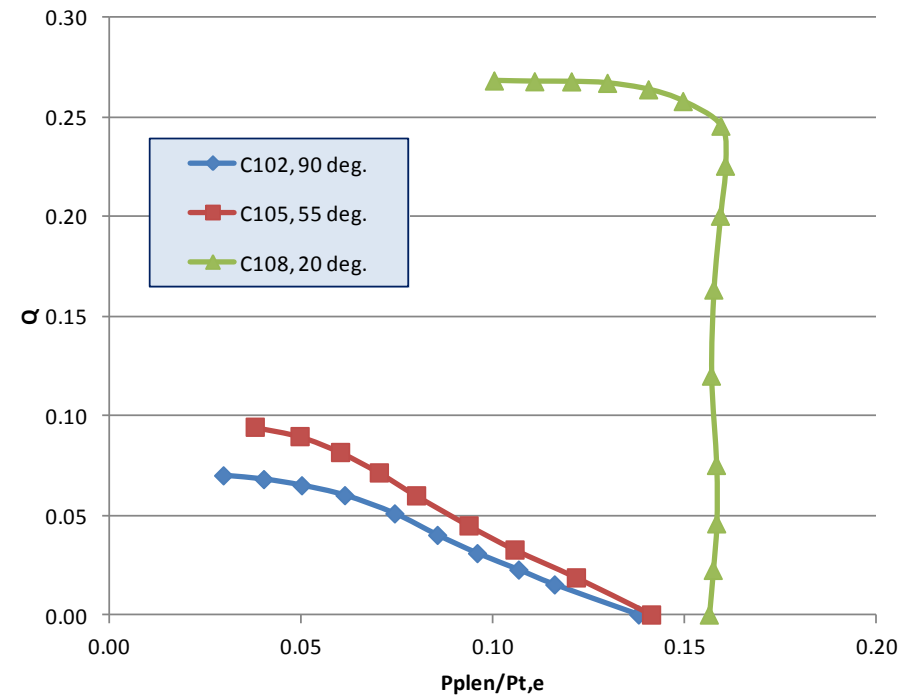
Effect of Hole Inclination Angle



$M=2, t/D=2.0$

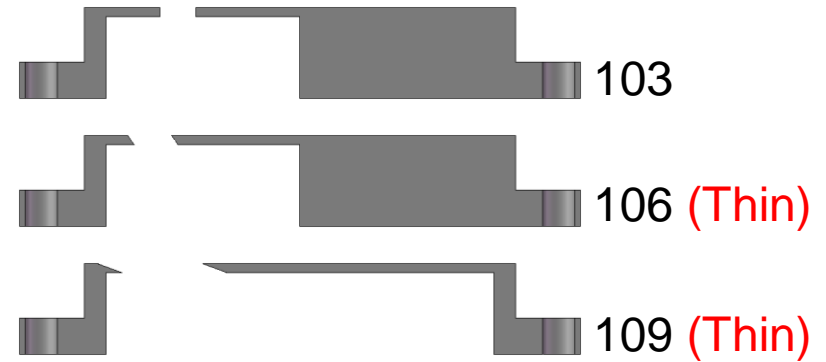


$M=2, t/D=1.125$

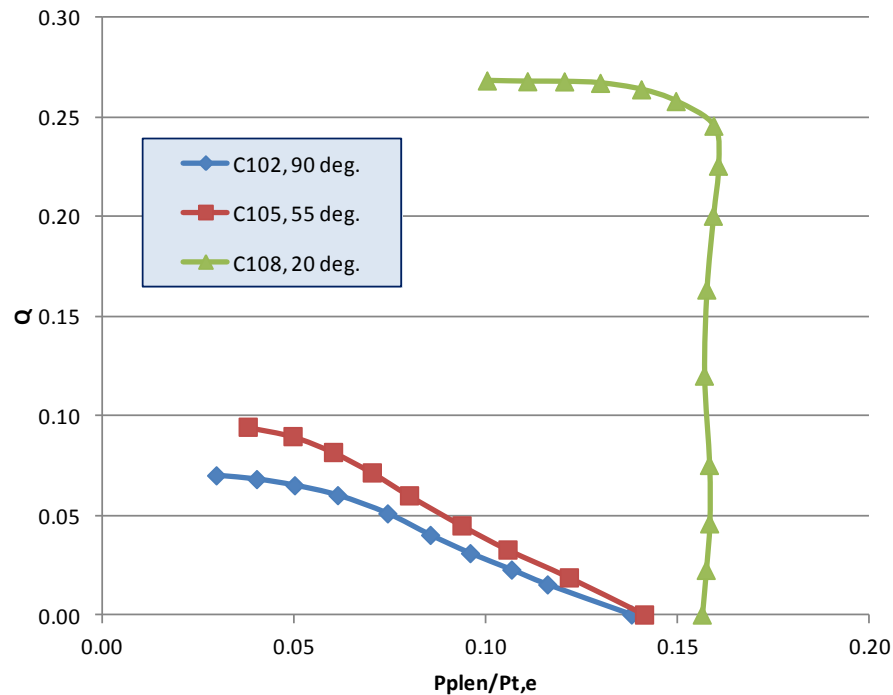




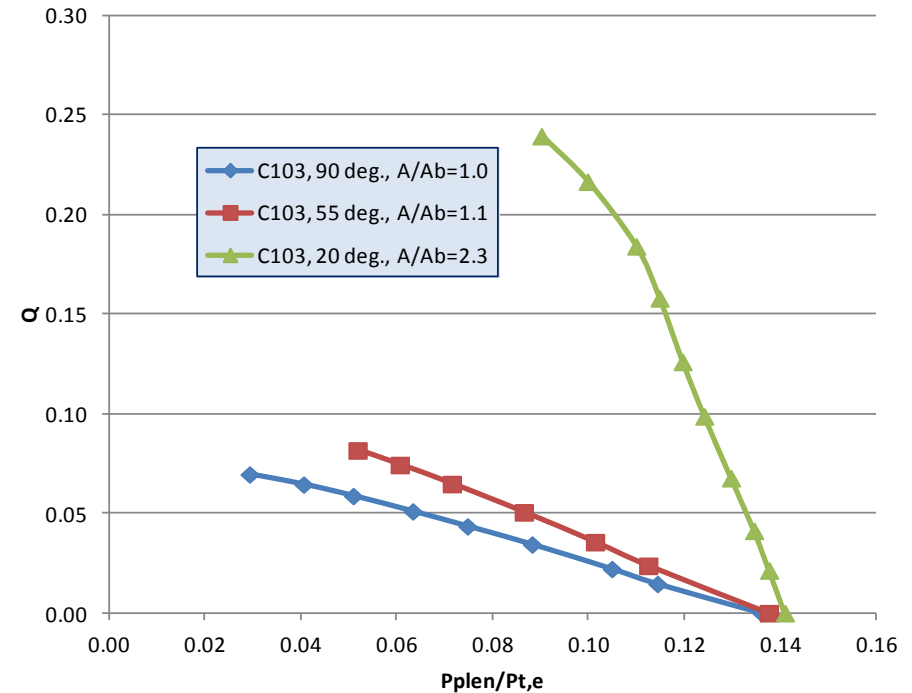
Effect of Hole Inclination Angle (cont).



$M=2$, $t/D=1.125$



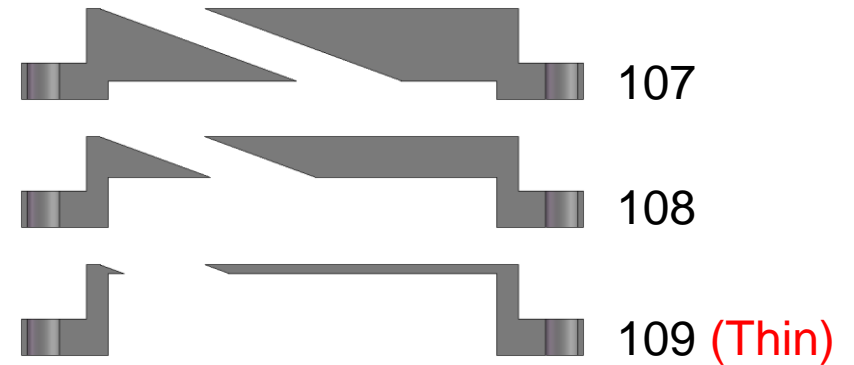
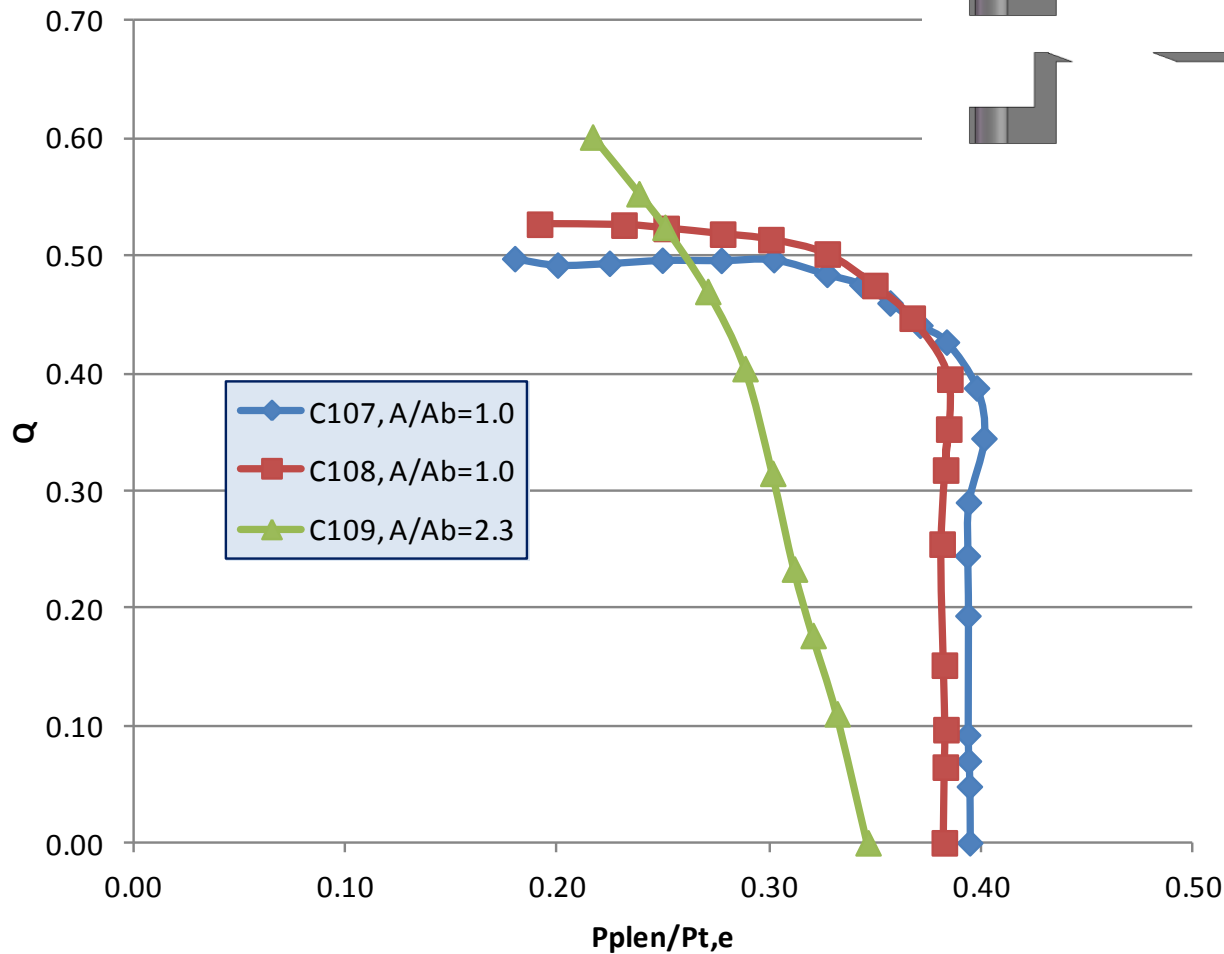
$M=2$, $t/D=0.25$





Thick vs. Thin Plate

M=1.4, 20 deg.

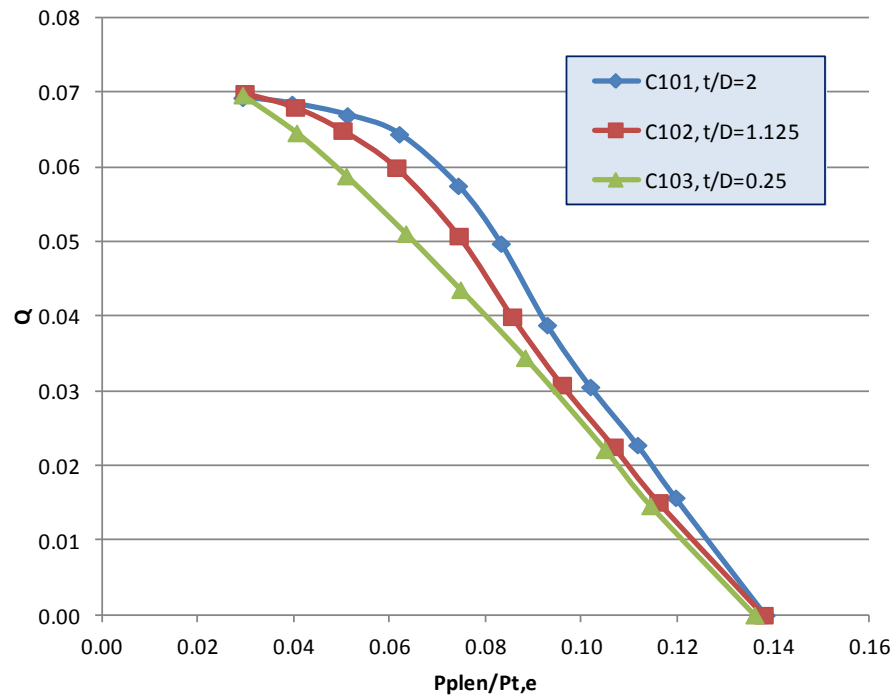




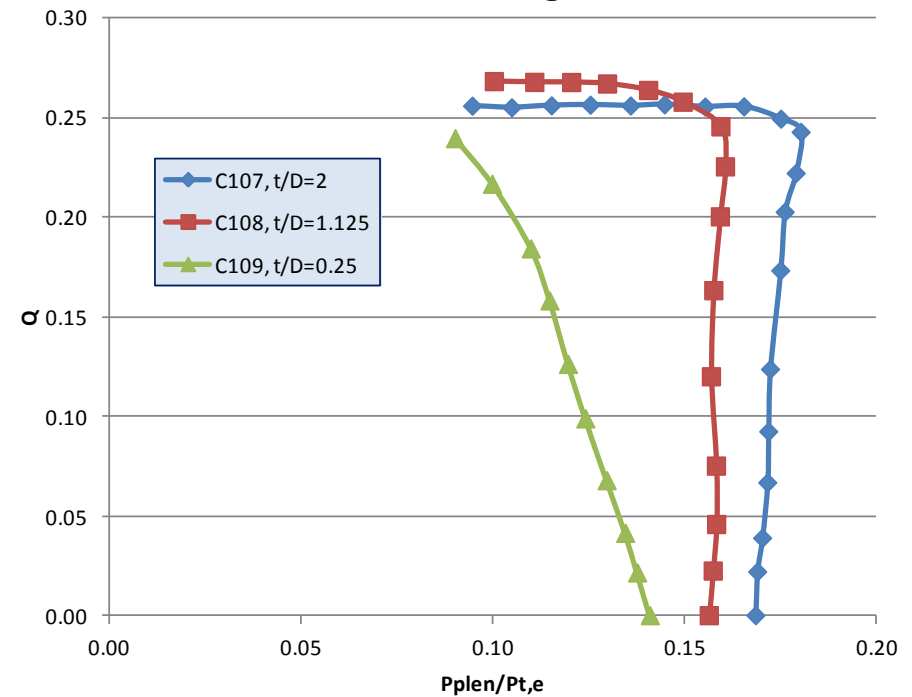
Effect of t/D



M=2, 90 deg.

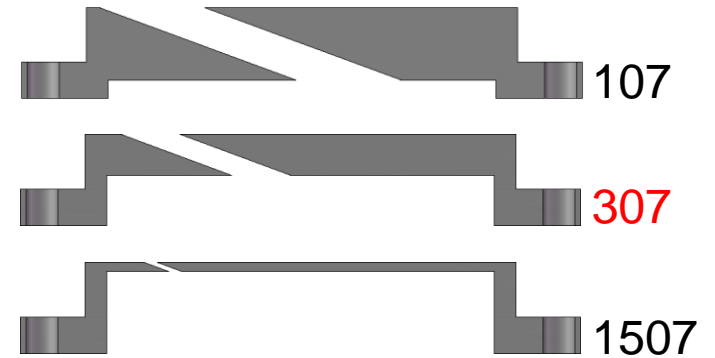


M=2, 20 deg.

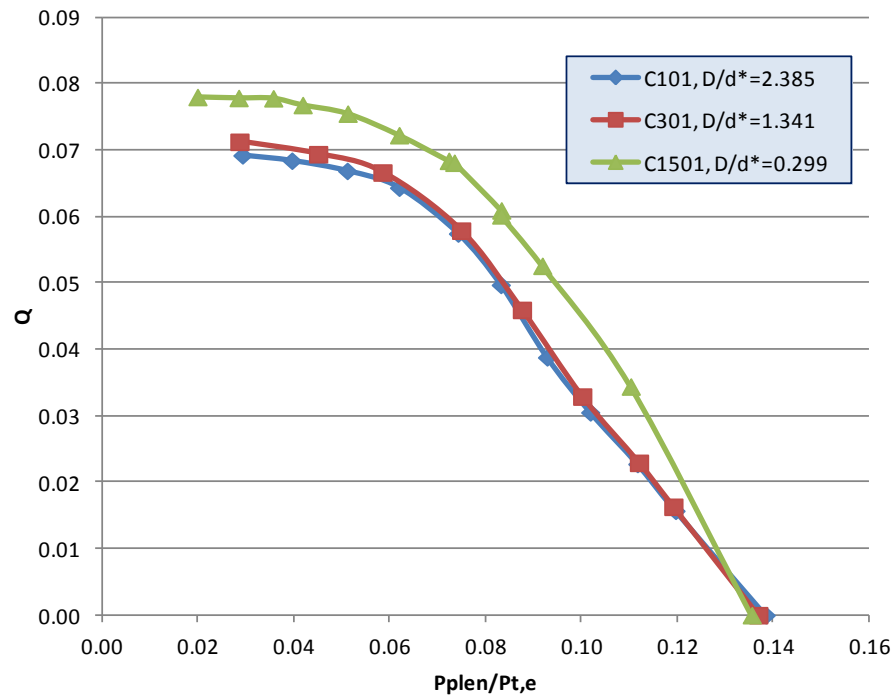




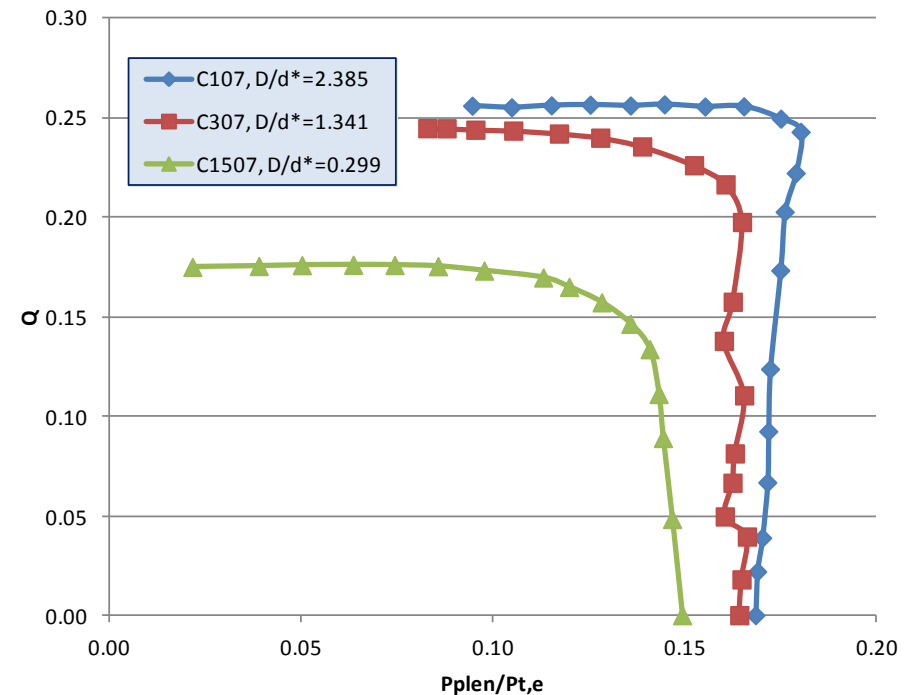
Effect of D/δ^*



$M=2$, 90 deg., $t/D=2.0$

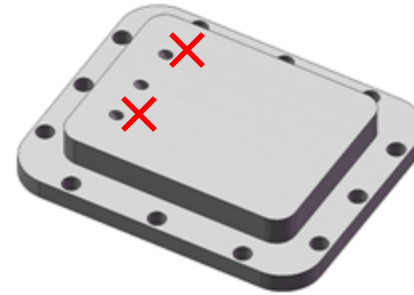


$M=2$, 20 deg., $t/D=2.0$



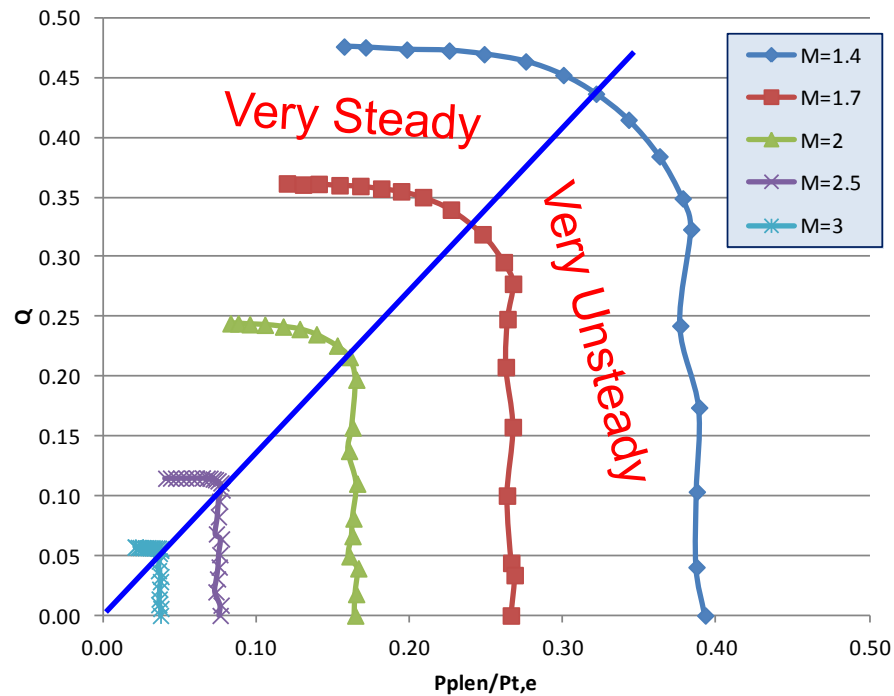


Unsteady Observation

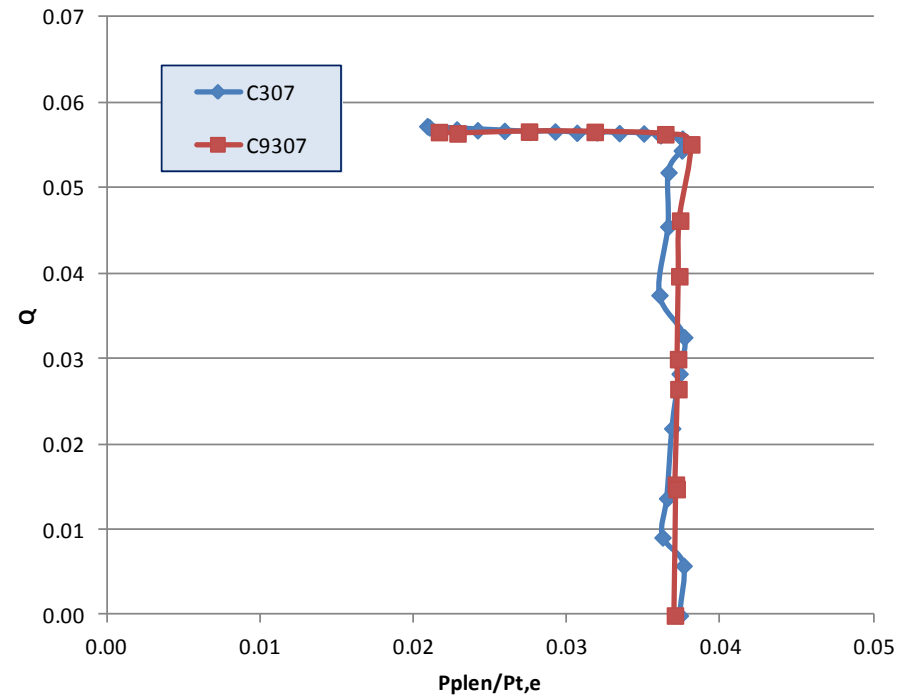


9307 has
outboard holes
of 307 plugged

C307, 20 deg., $t/D=2$



$M=3$, 20 deg., $t/D=2$





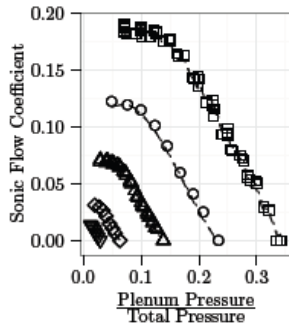
Preliminary Statistical Model

$$Q_{scaled} = \sum_{i=1}^{N_t} c_i \cdot I_i$$

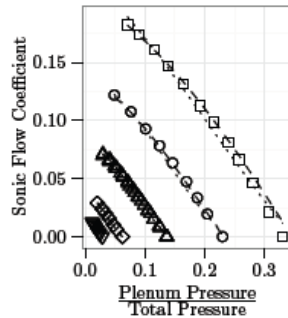
Model excludes 20° data

..... Nt = 26

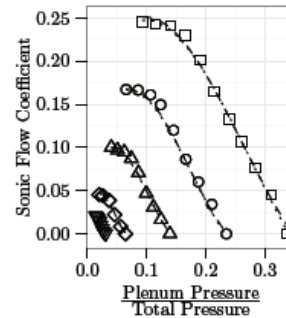
- - - - Nt = 43



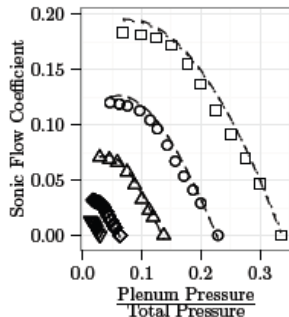
(a) Plate 101: $\alpha = 90^\circ$, $D = 6.339$ mm, $t/D = 2.011$



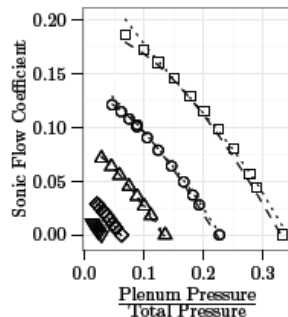
(b) Plate 103: $\alpha = 90^\circ$, $D = 6.337$ mm, $t/D = 0.259$



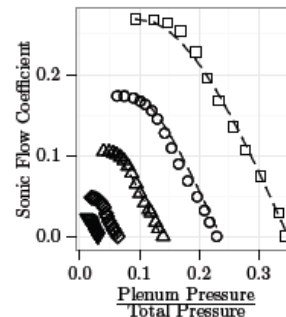
(c) Plate 104: $\alpha = 55^\circ$, $D = 6.354$ mm, $t/D = 2.005$



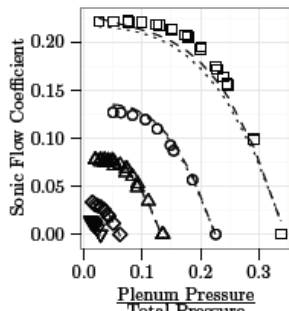
(d) Plate 301: $\alpha = 90^\circ$, $D = 3.585$ mm, $t/D = 1.984$



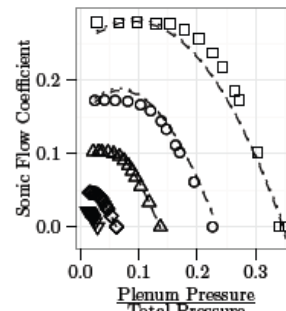
(e) Plate 303: $\alpha = 90^\circ$, $D = 3.561$ mm, $t/D = 0.266$



(f) Plate 304: $\alpha = 55^\circ$, $D = 3.545$ mm, $t/D = 2.002$



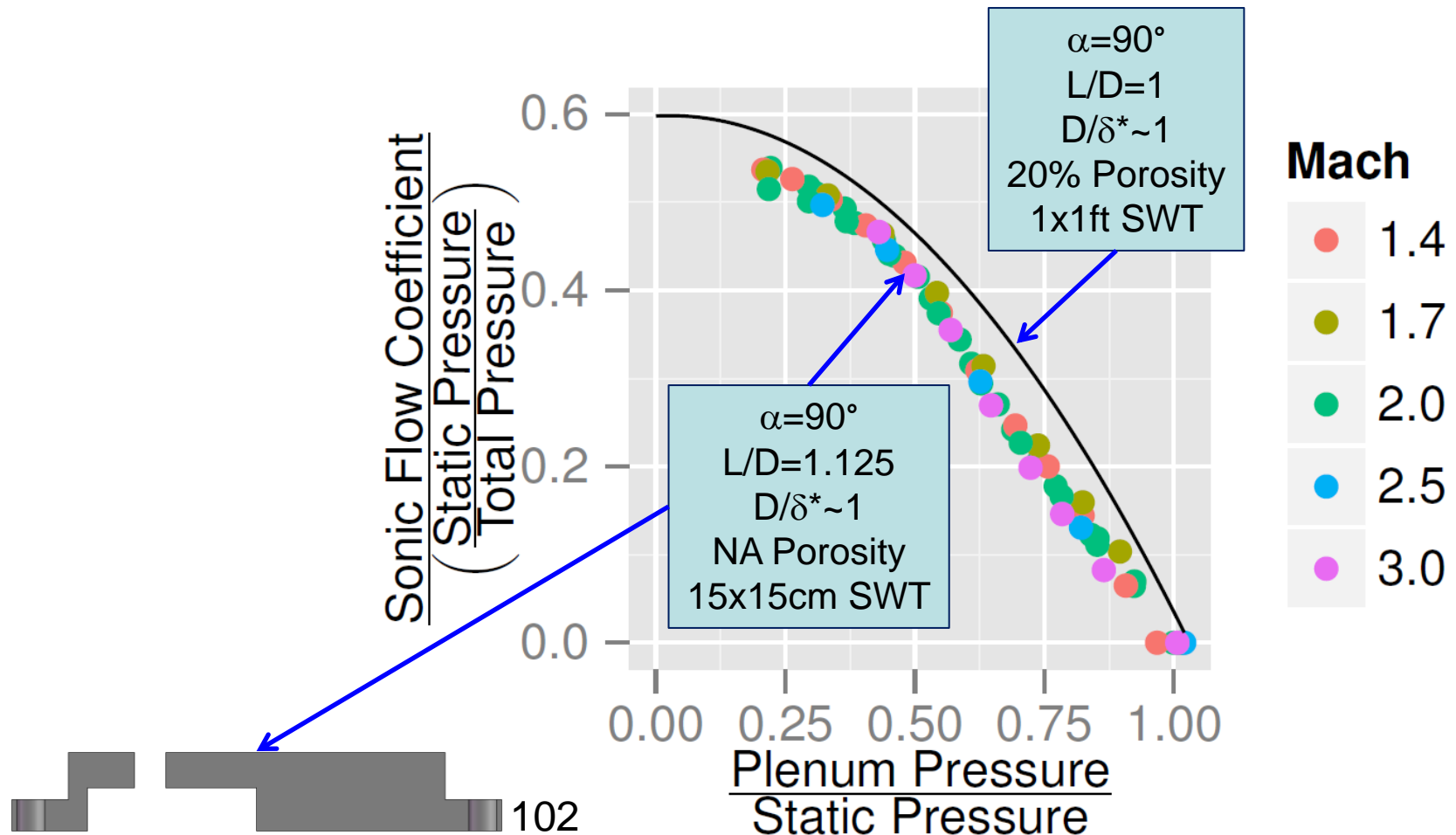
(g) Plate 1501: $\alpha = 90^\circ$, $D = 0.794$ mm, $t/D = 2.115$



(h) Plate 1504: $\alpha = 55^\circ$, $D = 0.794$ mm, $t/D = 2.003$



Flow Coefficient Scaling



FIBE Phase III testing to look at multi-hole arrays under same conditions as isolated holes.



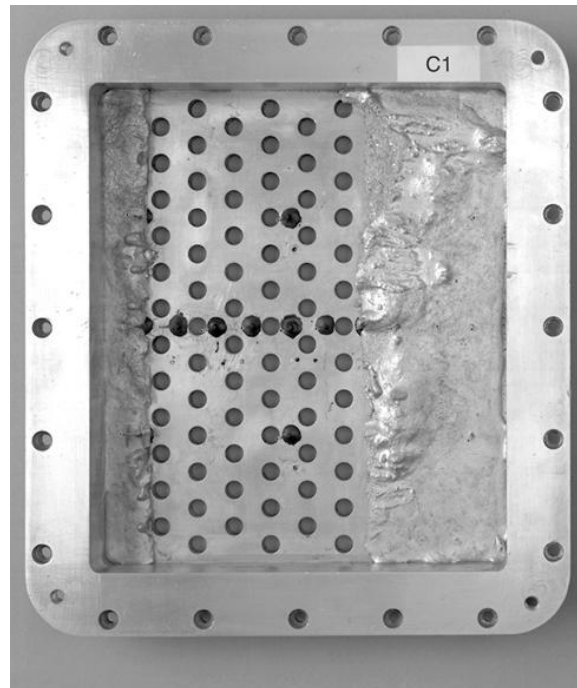
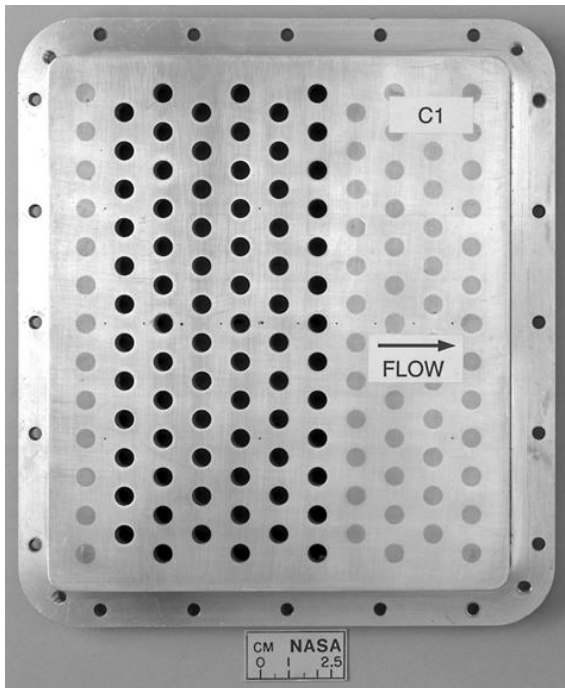
Phase II Summary

- Comprehensive isolated-hole flow coefficient database obtained.
 - Some cases incomplete surveys due to bleed capacity limitations.
 - Plenum dynamic pressures recorded.
- Analysis and model development continues at CWRU
 - M. Eichorn MS Thesis (Summer 2013)
 - Improved statistical model
 - Flow physics based model
 - Unsteady pressure data analysis



FIBE PHASE III TEST PLANNING

- Near Term – Flow Coefficient for Hole Arrays
 - 15x15cm SWT – Same flow conditions as Phase II
 - Initially focus on 90° holes with same parameters as Phase II
 - Porosity 10, 20, 30, 40%
 - Accumulate data with $N_{\text{row}}=1, 2, 3$, etc



Rows filled with Cerrobend
(low melting point alloy)

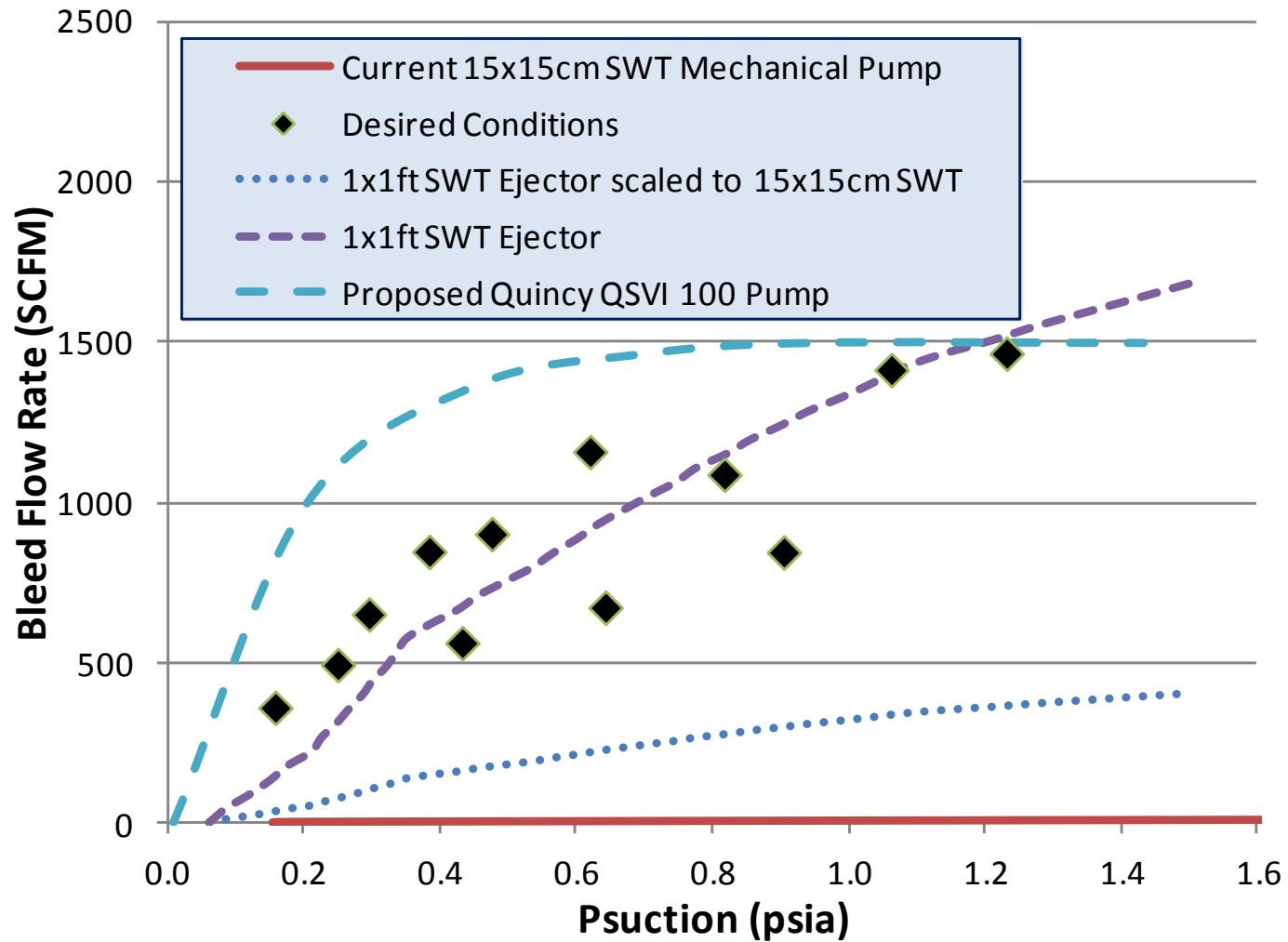


FIBE Phase III

- 15x15cm SWT Bleed Capacity Upgrade
 - Current mechanical Stokes pump capacity limits bleed configurations to isolated-hole.
 - Not adequate for all the configurations of Phase II
 - To perform Phase III testing, target is to have ability to remove 100% of the boundary layer on two walls of the tunnel over Mach number range from 1.4 to 3.0.
 - Proposal submitted to NASA GRC Technology Investment Fund
 - TIF funds \$100K (later augmented to a higher level)
 - Proposal total cost \$57K (excludes some installation costs)



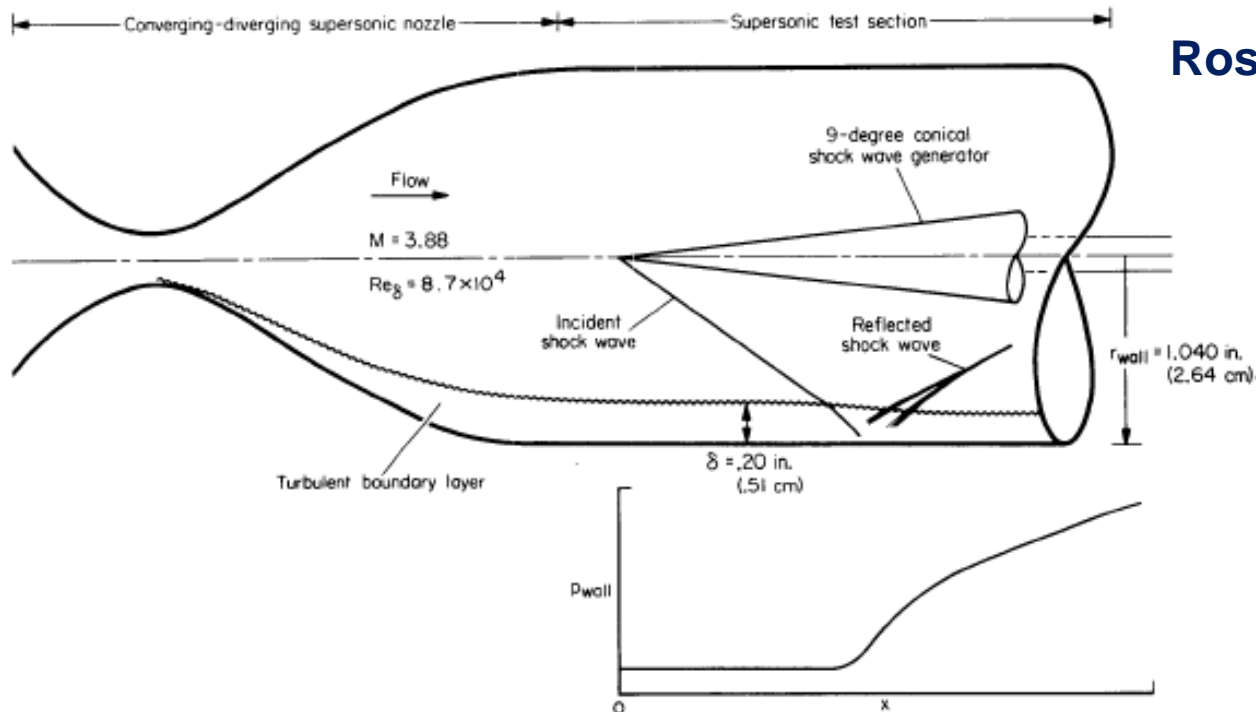
FIBE Phase III



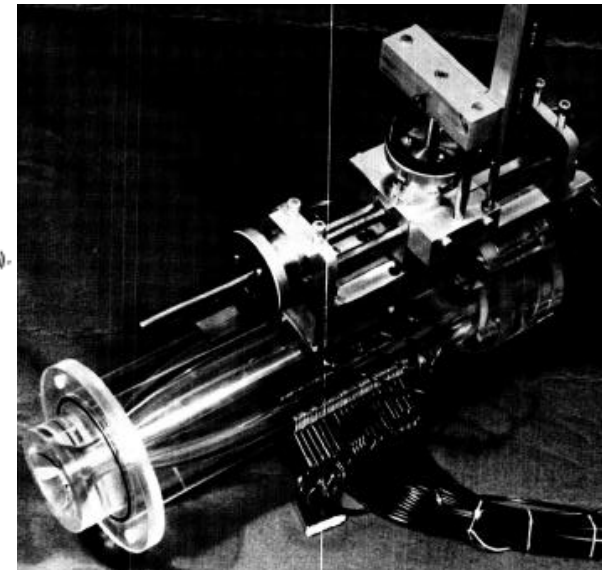


FIBE Phase III

- 15x15cm SWT Axisymmetric Test Section
 - Genesis from CFD Turbulence Model Validation Experiments
 - NASA FAP Aero Sciences Project study.
 - Also appropriate for “Cornerless Bleed Experiments”
 - Test Section Diameter ~ 17cm (6.7in)
 - Still need enhanced bleed capacity.



Rose, 1973, NASA TN D-7029





Questions?